SECTION II.—GENERAL METEOROLOGY.

THE EFFECT OF WEATHER UPON THE YIELD OF CORN.

By J. WARREN SMITH, Professor of Meteorology.

[Dated Weather Bureau, Columbus, Ohio, Jan. 5, 1914.]

INTRODUCTION.

The geographical distribution of vegetation is determined by the climate, and the principal climatic factors that must be considered in the development of plants in any part of the country are temperature, rainfall, and sunshine.

Temperature is the most important factor in determining the broad climatic belts within which different plants will grow and mature, as well as the more narrow belts where they will make their best development.

Investigation has shown that every plant has its optimum temperature and moisture values during which it makes its best development, and that this varies in different periods of its growth. And not only this, but the heat and moisture must be in right proportion.

The moisture in the soil carries the plant food to the roots to be worked into vegetable tissue by the energy of the solar rays. If there is not enough material brought to the plant then the solar energy is wasted, and on the other hand if the heat is not sufficient to use up the material brought by the moisture then the material is wasted.

In the highest altitudes there is an excess of moisture and a deficiency of heat. These are the conditions that obtain in most of Europe, and in these countries the crop yields are determined largely by the temperature.

In other places where the rainfall is sufficient and the temperature too low for the best growth of plants, such as in Alaska, the sunshine becomes the most important factor.

No plant life is perfected and reaches its fullest maturity except through the influence of the short waves of solar energy which we call light. Dark rays or heat can not replace sunlight in the growth of vegetation, but sunlight can partially replace heat. Barley and oats and similar crops can be cultivated, as they are, as far north as 70° latitude only because of the quantity of light.

A value called the "sunshine-hour degree" may be obtained by multiplying the average daily heat necessary to grow and mature a crop by the total possible number of hours of sunshine from planting to harvesting.

If this is done for corn in the United States the sunshine-hour degrees from the date of planting to the date of harvesting of corn for the district between latitude 30° and latitude 35° are found to be 80,313; between latitudes 35° and 40°, they are 65,778; and they amount to 47,887 between latitudes 40° and 45°; thus showing that the number of sunshine-hour degrees necessary to make a crop diminish as the latitude increases, and explaining further why there is a decided difference in the quantity of heat necessary for the same crop at different latitudes due to the difference in the quantity of light.

RAINFALL MOST IMPORTANT IN THIS LATITUDE.

In places where the temperature and sunshine are generally sufficient the development of the plant and more especially the crop yield depends most largely upon the rainfall. This is particularly true in most of the western part of the United States and to a large extent in central and eastern districts as well.

It has been demonstrated by long experiments in most of the temperate region that the yield of both grain and straw are greatest when the soil contains from 40 to 80 per cent of its full water capacity during the most active season of growth.

The most advantageous percentage of moisture varies with different plants, depending upon their method of using the water. In general the quantity of water necessary for a maximum crop increases with the richness of the soil, the closeness of the stand of plants, the size of the leaves, the dryness of the air, the velocity of the wind, and the temperature.

One writer states that it takes 350 tons of water to mature one acre of corn. Another, that unmulched land loses 200 barrels of water per acre each day by evaporation.

The grain plant obtains a great part of its total weight from the soil during the early part of its growth, and a lack of moisture at this time will cause a short straw but not necessarily a small yield of grain. During the latter part of the growth the seed is being made chiefly from material stored in the stalk, and moisture must be present to flush the material from the stalk into the head or the grain will be shrunken.

CRITICAL PERIODS OF GROWTH.

A careful study of the work of others as well as personal investigation leads the writer to the conclusion that all plants have a certain critical period when favorable weather will produce a good crop and unfavorable weather a poor crop. Also that it is quite possible to determine the most critical period as well as the weather element most affecting the conditions by a detailed study of the results in the field from the records of previous years.

In some crops this critical period is very short. In some, temperature seems to be the most important weather factor and in others it is the rainfall. In some crops the period seems to be soon after seeding and in others while in blossom. In apples, for example, our studies indicate that the weather during the formation of the fruit buds more than a year before the crop is harvested, has a greater effect upon the yield than that of any like period between these dates.

It seems to the writer that when the critical period for a crop has been determined, together with the meteorological factor most affecting it, and then the climate of a place calculated, the adaptability of that crop to that particular place can very quickly be determined. In some cases it will be possible to vary the variety, time of seeding, fertilizing (potassium nitrate hastens ripening), or cultivation, so as to bring the critical period into the time when most favorable weather conditions are most apt to prevail. In other cases it will be found best to substitute some other crop that will lend itself to these conditions. The one crop will do fairly well part of the time, while the other crop will reach its maximum most of the time.

Further, we believe that this critical period in most instances is long enough before the date of harvest to allow for giving more attention to other crops which perhaps may be substituted. For example, there is no question but the rainfall for May is the most important factor in the hay crop in most of the northern part of the United States. If, therefore, it is found toward the latter part of this month that the rainfall has been light, other forage crops may be planted to take the place of the small hay crop.

The critical period in the growth of corn.—The writer has devoted considerable time during the past 10 years to the problem of ascertaining just what effect the different weather factors have on the different crops and in trying to find the critical periods. A large amount of data has been brought together and some interesting and important results obtained.

As nearly 75 per cent of the world's production of corn is grown in the United States, and as the economic importance of this crop is so great, it has been thought best to prepare for publication the following discussion of the effect of weather upon corn.

It is not intended to be a complete or final study of the problem, because even as we are completing the paper we are constantly finding new problems and new lines of research which demand further attention. We believe it will show the methods used, however, and help to point out the most critical period in the growth of this important crop and the kind of weather that most affects the final yield.

JULY RAINFALL AND CORN YIELD IN OHIO.

In the Yearbook of the United States Department of Agriculture for 1903, page 215, the writer gave a short article upon the relation of precipitation to the yield of corn. The yield in each of the eight large corn-producing States in the central part of the country was compared with the rainfall during June, July, and August by means of curves.

The most important fact brought out in this article was the close relation between the rainfall for the month of July alone and the yield of corn. The yield curve for the eight States compared almost as closely with the rainfall curve for July alone as it did with the rainfall curve for the three months combined or with any two of them. The period coverd was from 1888 to 1902, inclusive.

A correlation method.—While the curve method of showing a relation between two factors is the most graphic, it is not the most accurate. Hence in Table 1 we have compared the average rainfall for the month of July for Ohio with the average yield of corn for the whole State for a period of 60 years by the simplest form of the correlation table.

As this form of correlation has been used very freely throughout this paper and as it may not be familiar to all of its readers the method will be explained in detail in discussing Table 1. (See also Monthly Weather Review, 1911, v. 39, p. 792.)

Eight columns are used in the table. Column 1 indicates the items, which in this case are the years from 1854 to 1913, inclusive, a period of 60 years.

Column 2 gives the average rainfall for the State of Ohio for the month of July for each of these years. Column 3 shows the departure of the rainfall for each year, from the average or normal for the month. In column 4 these departures from the normal have simply been squared.

In column 5 there has been entered the average yield of corn for the State of Ohio for each year, in bushels per acre. Column 6 gives the difference between the yield for each year and the normal or average for a long period.

The average yield of corn for Ohio for the 60 years is 34.5 bushels per acre. A careful inspection of the yield figures, however, will show a gradual increase in the yield during much of the time, and instead of taking the difference between the yield for each year and the average for the whole period it seemed best to use the mean for each 20 years in determining the departure figures for column 6. The average yield of corn for the period from 1854 to 1873 was 32.9 bushels per acre; from 1874 to 1893, 33.5 bushels per acre; and from 1894 to 1913, 37 bushels per acre. Inasmuch as a mean yield was determined for each 20 years in showing the departure from the normal the rainfall departures in column 3 were obtained for the same years in the same manner. It will be noticed also that the yield figures are given to tenths while the departure figures are to the nearest whole number.

The figures in column 7 are the square of the departure figures in column 6 and correspond with column 4.

In column 8 there is given the product of the two departure columns 3 and 6. Care must be taken in this column to place the proper sign before the figures, remembering that in multiplying like signs produce "plus" and unlike signs "minus" values.

The next step in the calculation is to obtain the sums of columns 4 and 7, multiply them together and obtain the square root of the product. The sum of column 4 is 111.83 and of column 7, 1,045. The product of these factors is 116,862.35 and the square root of this product is 341.8.

The next step is to obtain the algebraic sum of the values in column 8. This is +203.2 and this must be divided by 341.8 the square root of the product of the sums of columns 4 and 7. This gives a quotient of +0.59 which is called the "*correlation coefficient*" or *r*.

In this method of correlation if there is an *exact* relation between the two factors under discussion the correlation coefficient will be either +1 or −1. That is to say, if every time the rainfall was increased a certain amount the yield of corn was increased in exactly the same ratio then the correlation coefficient would be exactly +1. And on the other hand if every time the rainfall was increased a certain definite amount the corn yield would be *decreased* in an exact ratio the correlation coefficient would be exactly −1.

So in this correlation, the nearer the correlation coefficient, *r*, approaches 1 the closer the relation, and the nearer it approaches 0 the less the relation. Some writers believe that the relation or influence of one factor upon another is well established if the correlation coefficient is three times the probable error, while others think that it should be six times the probable error. It probably is safest to assume that there may be some relation if the correlation coefficient is three times the probable error and that the relation is established beyond question if it is more than six times the probable error.

The probable error is found by the following equation in which r is the correlation coefficient and n the number of years under consideration.

$$0.674\frac{1-r^2}{\sqrt{n}}$$

Substituting the values obtained in Table 1 we have the equation:

$$0.674\frac{1-(0.59)^2}{\sqrt{60}}$$

which equals ± 0.057 which is only $\frac{1}{10}$ of the correlation coefficient. This shows without question a very high correlation between the July rainfall and the yield of corn in Ohio covering a 60-years record.

TABLE 1.—*Correlation of July rainfall, and the yield of corn in Ohio, 1854 to 1913.*

Year.	July rainfall.			Corn yield.			3×6
1	2	3	4	5	6	7	8
	Amount.	Departure.	Square of departure.	Amount.	Departure.	Square of departure.	
	Inches.	*Inches.*		*Bushels.*	*Bushels.*		
1854	2.6	−1.5	2.25	26.0	−7	49	+10.5
1855	5.8	+1.7	2.89	39.7	+7	49	+11.9
1856	2.6	−1.5	2.25	27.7	−5	25	+ 7.5
1857	4.9	+0.8	.64	36.6	+4	16	+ 3.2
1858	4.7	+0.6	.36	27.7	−5	25	− 3.0
1859	1.6	−2.5	6.25	29.5	−3	9	+ 7.5
1860	5.8	+1.7	2.89	38.2	+5	25	+ 8.5
1861	3.3	−0.8	.64	33.5	+0.4	....	− 0.3
1862	3.6	−0.5	.25	30.0	−3	9	+ 1.5
1863	2.6	−1.5	2.25	27.0	−6	36	+ 9.0
1864	2.1	−2.0	4.00	27.0	−6	36	+12.0
1865	5.7	+1.6	2.56	35.0	+2	4	+ 3.2
1866	5.1	+1.0	1.00	36.5	+4	16	+ 4.0
1867	3.2	−0.9	.81	29.8	−3	9	+ 2.7
1868	2.7	−1.4	1.96	34.4	+2	4	− 2.8
1869	4.8	+0.7	.49	28.4	−4	16	− 2.8
1870	4.7	+0.6	.36	37.5	+5	25	+ 3.0
1871	3.7	−0.4	.16	36.7	+4	16	− 1.6
1872	6.7	+2.6	6.76	40.9	+8	64	+20.8
1873	6.2	+2.1	4.41	35.1	+2	4	+ 4.2
1874	3.8	−0.1	.01	39.2	+6	36	− 0.6
1875	6.9	+3.0	9.00	34.2	+1	1	+ 3.0
1876	6.4	+2.5	6.25	36.9	+3	9	+ 7.5
1877	3.7	−0.2	.04	32.5	−1	1	+ 0.2
1878	5.4	+1.5	2.25	37.8	+4	16	+ 6.0
1879	4.2	+0.3	.09	34.3	+1	1	+ 0.3
1880	4.2	+0.3	.09	38.9	+5	25	+ 1.5
1881	3.6	−0.3	.09	31.0	−4	16	+ 1.2
1882	3.2	−0.7	.49	34.0	+0.5	....	− 0.4
1883	4.2	+0.3	.09	24.2	−9	81	− 2.7
1884	3.8	−0.1	.01	33.3	−0.2	....	....
1885	3.2	−0.7	.49	36.8	+3	9	− 2.1
1886	2.9	−1.0	1.00	33.5	−0.03	....	....
1887	2.2	−1.7	2.89	30.5	−3	9	+ 5.1
1888	4.4	+0.5	.25	38.9	+5	25	+ 2.5
1889	4.2	+0.3	.09	32.3	−1	1	− 0.3
1890	2.0	−1.9	3.61	24.6	−9	81	+17.1
1891	3.8	−0.1	.01	35.6	+2	4	− 0.1
1892	3.8	−0.1	.01	33.3	−0.2	....	....
1893	2.5	−1.4	1.96	29.1	−4	16	+ 5.6
1894	1.6	−2.6	6.76	32.6	−4	16	+10.4
1895	2.0	−2.2	4.84	33.7	−3	9	+ 6.6
1896	8.1	+3.9	15.21	41.7	+5	25	+19.5
1897	4.6	+0.4	.16	34.3	−3	9	− 1.2
1898	4.0	−0.2	.04	37.4	+0.4	....	− 0.1
1899	4.2	+0.01	.0001	38.1	+1	1	....
1900	4.6	+0.4	.16	42.6	+6	36	+ 2.4
1901	2.7	−1.5	2.25	30.0	−7	49	+10.5
1902	4.7	+0.5	.25	38.8	+2	4	+ 1.0
1903	3.7	−0.5	.25	31.5	−6	36	+ 3.0
1904	4.1	−0.1	.01	32.8	−4	16	+ 0.4
1905	3.9	−0.3	.09	37.9	+1	1	− 0.3
1906	5.1	+0.9	.81	42.2	+5	25	+ 4.5
1907	5.4	+1.2	1.44	34.8	−2	4	− 2.4
1908	4.1	−0.1	.01	36.1	−1	1	+ 0.1
1909	3.8	−0.4	.16	38.7	+2	4	− 0.8
1910	3.2	−1.0	1.00	36.6	−0.4	....	+ 0.4
1911	2.4	−1.8	3.24	38.6	+2	4	− 3.6
1912	5.7	+1.5	2.25	42.8	+6	36	+ 9.0
1913	5.2	+1.0	1.00	37.8	+1	1	+ 1.0
Sum	....	....	111.83	....	....	1,045	+203.2

Correlation with other months.—It follows that by making similar correlations for other periods in the growth of the corn plant the time when the rainfall has the greatest effect can be accurately determined. The Weather Bureau records show monthly amounts of rainfall, hence in these early data the rainfall for complete months only can be used.

Correlation coefficient tables for Ohio for 60 years for other months worked out exactly as shown in Table 1 give the following:

Period of rainfall.	Correlation coefficient r
July	+0.59
June	+0.12
August	+0.37
June and July	+0.48
July and August	+0.67
June, July, and August	+0.57

This makes it plain that the rainfall for the month of July has a far greater effect upon the yield of corn in Ohio than either June or August, somewhat greater than the rainfall for June and July combined, and slightly greater than for June, July, and August combined, but that the rainfall for July and August combined has a greater effect than for July alone.

Results of variations in July rainfall.—The average rainfall for the State of Ohio in July for the past 60 years is 4.06 inches. The average yield of corn for Ohio for the 60 years is 34.5 bushels per acre. If the different years are grouped by July rainfall amounts the yield figures show some very interesting results.

For example, if all of the rainfalls of one-fourth inch differences be grouped and the yield figures averaged, the results will show an average increase in the yield of corn of 0.8 bushel per acre with each increase in the rainfall of one-fourth inch. That is, if all of the years when the rainfall for July was less than 1.75 inches, be grouped together then all of the years when the rainfall was between 1.75 inches and 2 inches, between 2 inches and 2.25 inches, and so on up to 8 inches, the increase in the average yield values will amount to 0.8 bushel per acre with each rainfall increase. Between 2 and 4 inches the average increase in yield with each increase in the rainfall of one-fourth inch amounts to 1.4 bushels per acre.

If the rainfall amounts are grouped for each half-inch difference, the average increase in the yield with each increase in the July rainfall of one-half inch is 1.2 bushels per acre. The average yield of corn for all of the years when the rainfall for July was between 2.50 inches and 3 inches is 29.8 bushels per acre, while the average yield for all of the years when the rainfall was between 3 inches and 3.50 inches was 34.1 bushels per acre. This is an average increase of 4.3 bushels per acre in the corn yield for the whole State of Ohio when there is an increase in the rainfall of only one-half inch, at what seems to be the critical rainfall stage in July.

The average increase in the corn yield with each increase of 1 inch in the rainfall in July in Ohio is 2.3 bushels per acre. Between 2 inches and 6 inches the yield increases at an average rate of 2.5 bushels per acre for each increase of 1 inch in the July rainfall. The greatest rate of increase is when the rainfall passes the 3-inch mark.

In all of the years when the rainfall in July in Ohio has averaged less than 3 inches the average corn yield has been 30.3 bushels per acre. In the years when the rainfall for July has been 5 inches or above, the corn yield has averaged 38.1 bushels per acre.

The records of crop production show that the area devoted to corn in Ohio for the 10 years from 1903 to 1912, inclusive, has averaged slightly over 3,500,000 acres each year. The average farm price for corn on December 1 during the same period has been 50 cents per bushel in Ohio.

Combining these figures with the yield values in the preceding paragraphs we see at once that each increase of one-fourth inch in rain in July over the State of Ohio causes an average increase in the total corn yield of 2,800,000 bushels, with a value of $1,400,000. Also that between 2 and 4 inches each increase in rain amounting to one-fourth inch increases the value of the corn crop in Ohio $2,950,000.

The figures show further that each increase in the rainfall in July of one-half inch will cause an average increase in the corn yield in Ohio of 4,200,000 bushels, worth on December 1 on the farm $2,100,000. And not only that, but when the rainfall for July passes the 3-inch mark the increase in the corn crop with an increase in the rainfall of only one-half inch will, on the average, amount to 15,050,000 bushels, worth $7,525,000 when corn is worth 50 cents a bushel on the farm.

For each variation of 1 inch in the rainfall for July the corn yield in Ohio varies 2.3 bushels per acre or 8,050,000 bushels.

When the rainfall for July in Ohio has been less than 3 inches the yield of corn has averaged 30.3 bushels per acre, and when the fall has been 5 inches or more the yield has averaged 38.1 bushels per acre. This difference of 7.8 bushels per acre means 27,300,000 bushels of corn for the State, worth $3.90 an acre, or $13,650,000, depending on whether the State has had an average of 3 inches or less of rain in July or whether the fall has been 5 inches or more.

It must be remembered that these figures are only averages and it does not follow that the yield will vary as indicated every time that the rainfall for July varies one-fourth or one-half inch, etc. Sometimes the variation will be greater and sometimes less, but inasmuch as the study covers the unusually long period of 60 years the figures must be valuable.

The practical application of this study comes in recognizing the fact that one-fourth and even one-half an inch of rain can be conserved from rapid evaporation by proper cultivation.

CORRELATION FOR SHORTER PERIODS THAN MONTHS.

The rainfall in the preceding correlations and discussions was for complete months so the next step seemed to be the tabulation of the rainfall into shorter periods to try and determine the exact time during which the rainfall has its greatest effect upon the corn yield.

At first this was done by correlating the rainfall at one station for each 10 days with the yield of corn in the county in which the station is located. Wooster, Ohio, and Wayne County were considered with the following result:

TABLE 2.—*Correlation of rainfall at Wooster, Ohio, for each 10 days and yield of corn in Wayne County, 1891 to 1910.*

Periods.	Correlation coefficient r.
June 21 to 30	+0.31
July 1 to 10	+ .12
July 11 to 20	**+ .71**
July 21 to 31	+ .16
August 1 to 10	+ .56
August 11 to 20	+ .46
August 21 to 31	+ .14
September 1 to 10	+ .36

This gives such a high value of r for the 10 days from July 11 to 20 as compared with the periods on either side, that the reliability of comparing the rainfall at one point alone in a county with the yields for that county was seriously doubted.

We therefore calculated the average yield of corn for the three counties of Franklin, Madison, and Pickaway, in central Ohio, and the average rainfall for 18 coöperative stations in and around these counties. The period covered was from 1891 to 1910, inclusive, and we believe that a correlation with the averages obtained in this manner has a high degree of accuracy.

The same method of correlation was used as has been described in Table 1, and the correlation was made for each 10, 20, 30, 40, and 50 days, as shown by the following tables:

TABLE 3.—*Relation between rainfall and yield of corn in central Ohio for 10-day periods, 1891 to 1910.*

Periods.	Correlation coefficient r.
June 1 to 10	−0.09
June 11 to 20	+ .12
June 21 to 30	− .04
July 1 to 10	+ .16
July 11 to 20	+ .36
July 21 to 31	+ .36
August 1 to 10	**+ .52**
August 11 to 20	+ .29
August 21 to 31	− .06

This table seems to show plainly that the 10-day period from August 1 to 10 has the greatest influence upon the yield of corn in central Ohio. The probable error for that correlation coefficient is ±0.10, which is fairly low.

TABLE 4.—*Relation between rainfall and yield of corn in central Ohio for 20-day periods, 1891 to 1910.*

Periods.	Correlation coefficient r.
June 1 to 20	+0.03
June 11 to 30	− .10
June 21 to July 10	+ .07
July 1 to 20	+ .36
July 11 to 31	+ .41
July 21 to August 10	**+ .50**
August 1 to 20	+ .45
August 11 to 31	+ .20

The highest value of r in this table is +0.50 from July 21 to August 10, and this is just five times the probable error.

TABLE 5.—*Relation between rainfall and yield of corn in central Ohio for 30-day periods, 1891 to 1910.*

Periods.	Correlation coefficient r.
June 1 to 30	−0.02
June 11 to July 10	+ .11
June 21 to July 20	+ .26
July 1 to 31	+ .43
July 11 to August 10	**+ .49**
July 21 to August 20	+ .48
August 1 to 31	+ .37

Here the greatest coefficient is for the period July 11 to August 10, when r is +0.49, and the probable error is ±0.10. These last three tables seem to show that the rainfall before July 10 does not have a very great effect upon the yield of corn. Also that the rainfall after August 11 need not be taken very seriously into account. The tables show further that the correlation coefficient for the 10 days of August 1 to 10 is higher than for any 20 or any 30 day period, although the difference is slight.

TABLE 6.—*Relation between rainfall and yield of corn in central Ohio for 40-day periods, 1891 to 1910.*

Periods.	Correlation coefficient r.
June 1 to July 10	+0.07
June 11 to July 20	+ .24
June 21 to July 31	+ .36
July 1 to Aug. 10	+ .53
July 11 to August 20	**+ .60**
July 21 to August 31	+ .52

There seems little question in this table of the dominating influence of the rainfall during the period from July 11 to August 20. This correlation coefficient of +0.60 is nearly seven times the probable error.

TABLE 7.—*Relation between rainfall and the yield of corn in central Ohio for 50-day periods, 1891 to 1910.*

Periods.	Correlation coefficient r.
June 1 to July 20	+0.17
June 11 to July 31	+ .36
June 21 to August 10	+ .49
July 1 to August 20	**+ .59**
July 11 to August 31	+ .55

The correlation coefficient from July 1 to August 20 in this table is +0.59 and is slightly more than six times the probable error.

We believe that the district covered by the yield and rainfall figures in Tables 3 to 7 makes them very reliable and that the values may be taken as a standard for this section of the country. Similar tables should be worked out for other districts, however, as the correlations might vary under different distribution of rainfall or different temperature and sunshine.

It may be well again to call attention to the differences shown in Table 3 as compared with Table 2, in order to emphasize the importance of having sufficient data so that incorrect conclusions may be avoided.

WEATHER EFFECTS DURING DIFFERENT PERIODS OF DEVELOPMENT.

After showing the relation between the corn yield and a single element, the rainfall during certain definite periods, the question naturally arises: What is the effect of all the elements, i. e., the weather during different periods of development of the corn plant? This question can be answered by a study of certain data that have been compiled at Wauseon, Fulton County, Ohio.

Mr. Thomas Mikesell, of this place, has kept a most remarkable record of phenological data for the past 30 years. He has a wonderfully complete record of the advance o all field and garden crops, of fruit and forest trees, shrubs, grasses, weeds, etc., of all varieties, as well as of the migration of birds and the activities of insects, animals, etc. At the same time he has kept a daily record of temperature and rainfall with well-exposed standard instruments.

In Table 8 there have been entered certain important data relating to corn growth and development from 1883 to 1912 as taken from the records of Mr. Mikesell. As will be seen, they cover the dates planted, dates that the plants appear above ground, the date in blossom, and the date ripe, together with a statement of the quantity and quality of the crop.

From 1883 to 1901 the dates are for operations on his own farm, and during the balance of the period for certain nearby fields, the same field being used for the entire season. The average dates and periods of development are given at the bottom of the table.

TABLE 8.—*Phenological dates and data for growth of corn at Wauseon, Ohio, 1883 to 1912, by Thomas Mikesell.*

[Lat., 41° 35′ N; long., 84° 07′ E.; alt., 780 feet A. M. S. L.]

Year.	Date planted.	Date above ground.	Days from planting to above ground.	Date in blossom.	Days from above ground to blossom.	Date ripe.	Days from blossom to ripe.	Per cent of good crop.	Quality of crop.
1883	May 12	May 25	13	July 29	65	Oct. 10	73	60	Poor.
1884	16	24	8	24	61	Sept. 15	53	90	Good.
1885	18	25	7	23	59	26	65	65	Fair.
1886	11	19	8	17	59	15	60	85	Good.
1887	20	25	5	24	60	15	53	60	Fair.
1888	15	25	10	25	61	20	57	75	Fair.
1889	15	23	8	Aug. 3	72	30	58	85	Good.
1890	27	June 1	5	July 26	55	20	56	50	Fair.
1891	12	May 22	10	27	66	18	53	60	Good.
1892	June 18	June 23	5	Aug. 6	44	25	50	60	Fair.
1893	May 18	May 28	10	July 25	58	12	49	60	Good.
1894	1	10	9	17	68	Aug. 30	44	60	Fair.
1895	1	7	6	22	76	Sept. 10	50	80	Good.
1896	9	14	5	10	57	Aug. 30	51	100	Good.
1897	22	June 5	14	20	45	Sept. 12	54	80	Good.
1898	18	May 25	7	20	56	Aug. 31	42	...	...
1899	18	27	9	17	51	30	44	90	Good.
1900	...	...	...	...	...	Sept. 6	...	...	...
1901	May 12	May 27	15	July 18	52	5	49	...	...
1902[1]	...	...	...	...	...	3	...	...	...
1903	...	...	...	...	...	...	...	...	...
1904	May 7	May 17	10	July 25	69	Sept. 10	47	80	Good.
1905	9	15	6	18	64	Aug. 30	43	75	Good.
1906	10	16	6	17	62	Sept. 10	55	80	Good.
1907	Apr. 26	6	10	30	85	3	35	75	Good.
1908	May 21	28	7	30	63	15	47	80	Good.
1909	14	21	7	Aug. 6	77	25	50	80	Good.
1910	11	21	10	1	72	30	60	90	Fair.
1911	10	17	7	July 20	64	8	50	80	Fair.
1912	10	20	10	22	63	2	42	95	Good.
Average	May 14	May 23	9	July 25	62	Sept. 13	50	76	

[1] Data for the years 1883 to 1901, inclusive, apply to Mr. Mikesell's own estate; data for 1902 to 1912 apply to certain nearby fields, the same field being used for the entire season.

Thermal constants.—The "thermal constant" of a crop is the average sum of the daily mean temperatures necessary to bring it to maturity. Thermal constants have been worked out at many of the European experiment stations and it has been determined that the amount of heat necessary to bring a certain crop to maturity in the same locality does not vary very much in different years. If the temperature is comparatively low, the ripening is correspondingly delayed. But there have been marked differences among investigators as to the temperature data to be considered and the point from which the thermal constant should be calculated.

Botanists state that the protoplasmic contents of vegetable cells are inactive when the temperature is below 6° C. (42.8° F.); that the protoplasm begins to awaken into life when this temperature is reached, and will grow and multiply as the temperature rises above this point.

It seems to the writer that 43° F. should be adopted as the point of departure in calculating "thermal constants." Also that the daily temperatures used should be the mean of the daily maximum and minimum temperatures obtained in the shade. These are the daily means used by the United States Weather Bureau and are the most available. [Necessary corrections to be applied in obtaining the true daily mean temperature are given in Weather Bureau Bulletin S.]

For the spring-seeded crops we believe that the thermal constant or effective temperature record should begin with the date of seeding and end with the date of ripening. For fall-seeded crops the record should also begin with the date of seeding and all winter days be used when the mean temperature for the day is above 43°. It might be said that when grain is covered with snow an air temperature above 43° has no effect upon the plant. But on the other hand if the ground is not frozen the plant may be growing slightly while covered with snow even with the temperature over the snow cover below 43°. In the case of fruits it is probable that the "thermal constant" should be calculated from the beginning of the formation of the fruit buds during the preceding summer.

The method used for obtaining the "thermal constant" as noted above is quite simple. Thus if the mean temperature for any month is 65° F. the daily effective temperature is 65° minus 43°, or 22°. The thermal constant for the month will be found by multiplying the daily effective temperature, 22, by the number of days in the month.

If the daily mean temperature during any part of a month has been 43° or below, these days should be omitted and only those days used when the average daily temperature is 44° and above. This can be done by either of two methods: (1) Find the difference between the mean temperature and 43° for each day separately and add the sums together, or (2) get the mean temperature for the days when the mean is 44° and above, subtract 43°, and multiply by the number of days.

THERMAL AND RAINFALL CONSTANTS AT WAUSEON, OHIO.

Thermal and rainfall constants have been worked out for the different stages of growth of corn at Wauseon, Ohio, for 1883 to 1912, and appear in Table 9. In addition, the amount of available heat and the rainfall for 10 days before the date of planting was determined and appears in the table.

This table should be studied in connection with the data in Table 8 for the dates of planting, blossoming, etc., and the number of days between these dates during different years.

TABLE 9.—*Thermal and rainfall constants during the growth of corn at Wauseon, Fulton County, Ohio, 1883 to 1912.*

Year.	Thermal.						Rainfall.						
	10 days before planting.	Planting to above ground.	Above ground to blossoming.	Blossoming to ripening.	10 days before blossoming.	10 days after blossoming.	10 days before planting.	Planting to above ground.	Above ground to blossoming.	Blossoming to ripening.	5 days before to 5 days after blossoming.	10 days before blossoming.	10 days after blossoming.
	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
1883	139	141	1,583	1,264	270	290	0.6	2.7	13.7	6.1	0.7	3.7	0.0
1884	114	161	1,496	1,412	240	290	1.0	0.8	6.0	5.9	1.1	0.0	4.5
1885	114	147	1,520	1,432	330	340	0.1	1.6	6.6	8.4	1.8	0.2	2.6
1886	134	128	1,477	1,565	290	260	0.9	0.9	2.8	5.5	T.	T.	0.2
1887	205	131	1,693	1,371	350	330	0.1	1.4	8.4	1.9	1.0	1.0	0.0
1888	128	110	1,600	1,410	270	320	1.4	0.4	5.6	2.7	0.1	0.1	0.4
1889	250	143	1,649	1,239	250	240	1.3	0.4	15.3	2.3	1.0	1.6	0.9
1890	167	131	1,365	1,330	270	360	1.1	T.	4.4	6.3	T.	T.	T.
1891	103	148	1,568	1,366	260	250	0.4	0.6	6.6	4.0	0.4	0.4	0.4
1892	318	165	1,253	1,238	310	310	1.0	1.2	5.3	6.2	0.3	1.2	T.
1893	140	163	1,634	1,411	300	300	1.0	0.3	8.4	1.4	0.4	1.0	0.4
1894	139	161	1,638	1,309	290	330	0.9	1.3	5.3	1.1	0.2	T.	0.2
1895	157	175	1,919	1,428	250	270	T.	1.2	2.3	3.8	0.7	0.2	0.5
1896	235	154	1,443	1,490	280	290	0.2	0.6	8.2	13.8	4.0	1.4	6.4
1897	153	186	1,232	1,486	290	320	1.0	1.2	5.4	3.5	1.0	1.7	1.3
1898	150	177	1,566	1,259	...	...	1.7	1.4	6.1	4.7	...	...	...
1899	169	154	1,478	1,344	290	320	1.4	1.2	4.7	2.3	2.8	2.2	1.2
1900	...	...	...	...	...	...	...	...	...	...	...	...	...
1901	151	201	1,468	1,546	...	...	0.8	1.8	8.3	2.2	...	...	...
1902	...	...	...	...	...	...	...	...	...	...	...	...	...
1903	...	...	...	...	...	...	...	...	...	...	...	...	...
1904	146	109	1,637	1,140	290	270	0.1	0.6	6.5	3.6	0.8	1.6	0.6
1905	142	97	1,526	1,210	290	270	0.8	3.3	10.2	2.9	0.1	0.1	0.2
1906	91	127	1,574	1,607	300	280	0.6	0.4	6.8	6.1	0.3	2.3	0.2
1907	−25	36	1,762	897	290	160	0.4	0.8	10.7	3.3	1.4	1.3	2.0
1908	213	199	1,735	1,229	300	300	2.6	0.4	9.6	3.4	0.0	2.1	0.2
1909	135	107	1,984	1,223	310	300	2.5	0.4	10.7	6.0	0.5	1.1	2.6
1910	78	114	1,811	1,453	290	260	1.0	0.7	6.6	6.9	0.1	3.4	T.
1911	125	166	1,913	1,322	290	230	0.1	T.	10.2	5.0	1.1	1.0	0.8
1912	168	123	1,645	1,107	300	270	0.8	2.2	5.3	5.1	0.6	0.8	0.8
Means	150	143	1,599	1,337	296	286	0.9	1.0	7.4	4.6	0.8	1.1	1.1

In Table 8, for example, the average date for planting corn is May 14, and the average number of days for the plants to appear above the ground is nine. Table 9 shows that the average number of degrees during this period has been 143°, and the average rainfall 1 inch.

The average time from the date the plants appear above the ground until they are in blossom is 62 days, and the thermal constant averages 1,599°. The rainfall averages 7.4 inches. The average date that the corn is in blossom at Wauseon is July 25, although this date has varied between July 10 and August 6.

The average date that the corn has ripened is September 13, or 50 days after the date of blossoming. The average thermal constant during this time is 1,337°, and the average rainfall 4.6 inches.

Table 9 also gives the thermal and rainfall constants for 10 days before blossoming and for 10 days after blossoming, as well as the rainfall during the 10-day period from five days before to five days after blossoming.

Thermal constants and corn yield, Wauseon, Ohio.—In Table 10 the correlation coefficients have been given between the thermal constants during different periods of corn development and the percentage of a good crop, as reported by Mr. Mikesell. It is unfortunate that we do not have the yield of corn in bushels per acre, yet believe that the percentage figures have been carefully considered by the observer.

TABLE 10.—*Results of correlation between thermal constants and corn yield, Wauseon, Ohio, 1883 to 1912.*

Correlation factors.	Correlation coefficient r
(1) Thermal constants for 10 days before planting and yield	−0.03
(2) Thermal constants from date of planting to date above ground and yield	−.03
(3) Thermal constants from date above ground to date of blossoming and yield	+.18
(4) Thermal constants from date of blossoming to date ripe and yield	+.08
(5) Daily mean temperature for 10 days before blossoming and yield	−.003
(6) Daily mean temperature for 10 days after blossoming and yield	−.28

There is a slight positive relation between the temperature between the date that the corn appears above the ground and the date of blossoming and the yield of corn, as well as a negative relation between the temperature for 10 days after blossoming and the yield, but the correlation coefficients are all too low to be given any consideration.

Thus Table 10 seems to show that there is little or no relation between the daily mean temperature and the yield of corn.

Rainfall constants and corn yield, Wauseon, Ohio.—In Table 11 the correlation coefficients between the yield of corn and the rainfall during the different periods of growth are shown.

TABLE 11.—*Results of correlation between rainfall constants and corn yield, Wauseon, Ohio, 1883 to 1912.*

Correlation factors.	Correlation coefficient r
(1) Rainfall for 10 days before planting and yield of corn	+0.01
(2) Rainfall from date of planting to date above ground and yield	−.06
(3) Rainfall from date above ground to date of blossoming and yield	−.03
(4) Rainfall from date of blossoming to date ripe and yield	+.29
(5) *Rainfall from 5 days before blossoming to 5 days after blossoming and yield*	+.45
(6) Rainfall for 10 days before blossoming and yield	+.20
(7) **Rainfall for 10 days after blossoming and yield**	+.74
(8) Rainfall for 20 days after blossoming and yield	+.57
(9) Rainfall for 30 days after blossoming and yield	+.46

The results from this table are very important. It seems to make plain that there is no relation between the rainfall in the first part of the period of growth of the corn crop and the yield. The average date of blossoming as determined in Table 8 is July 25, 62 days after the plants appear above the ground and 71 days after planting.

The correlation coefficient for the first three items in Table 11 are much too near zero to receive consideration. The correlation coefficient in item 4 indicating the relation between the rainfall between the dates of blossoming and ripening is +0.29, but as this is only two and one-half times the probable error even this is not very close.

The value of r for the rainfall for 10 days before the date of blossoming as given in item 6 is also too low to be given serious consideration. In item 5, however, covering the time from five days before blossoming to five days after blossoming, the value of r is four times the probable error and a relation is apparently established.

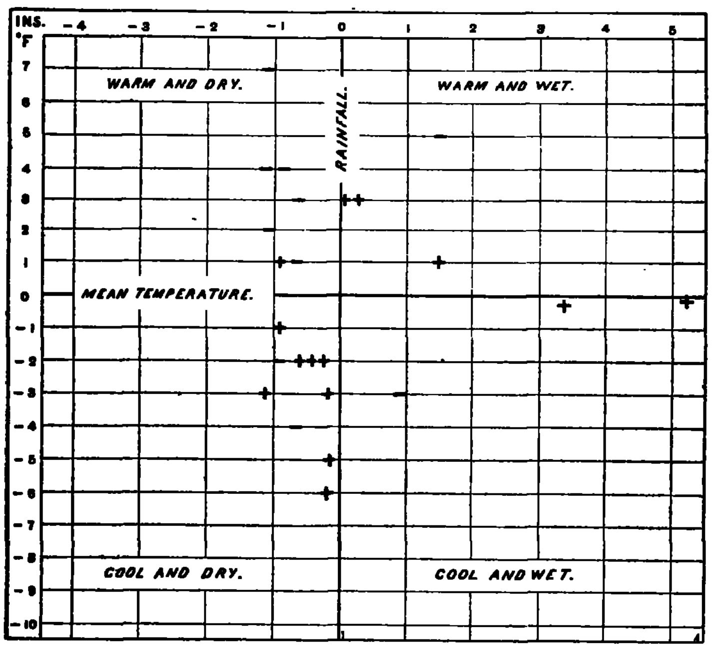

FIG. 1.—Dot chart showing combined effect of temperature and rainfall during the 10 days following the date of blossom upon the yield of corn at Wauseon, Ohio, 1883–1912. +, yield above normal; –, yield below normal.

It is in item 7 of Table 11, however, that we have the highest correlation coefficient. This shows that the rainfall for the 10 days after blossoming has the greatest effect upon the yield of corn of any period in the history of the plant. This value of r is +0.74, which is 15 times the probable error. This coefficient is considerably higher even than that for the 20 days or the 30 days following the date of blossoming.

In Tables 3, 4, and 5, there were given the correlation coefficients for the rainfall for the State of Ohio as a whole compared with the yield of corn, for arbitrary 10, 20, and 30 day periods. All near the average date of blossoming gave high values of r. These facts combined with the high value of r in item 7 of Table 11 go to show that the rainfall immediately after blossoming has a very dominating effect upon the yield of corn.

Combined effect of rainfall and temperature.—Item 7 in Table 11 indicates a direct relation between the rainfall for 10 days after blossoming and the yield of corn, and item 6 in Table 10 seems to show an opposite effect of the temperature upon the yield, during the same period.

In figure 1, therefore, the combined effect of these two factors is shown by a dot chart. In this chart the mean or normal temperature is indicated by a central horizontal line. Lines above this normal line indicate temperatures above the normal and lines below it temperatures below the normal. The normal rainfall is indicated by a central perpendicular line and the rainfall values above and below the normal are indicated by lines to the right and left of the central line, respectively.

The dot chart is made by placing a yield dot at the intersection of the lines indicating the departure of the temperature and the rainfall from the normal. If the yield is above the normal a cross or plus mark is entered, and if the yield is below the normal a minus sign is set down. If there is a decided effect of either or of both factors there will be a well defined grouping of the plus and the minus signs.

Figure 1 seems to make plain the fact that warm and dry weather for 10 days after blossoming is very damaging to the corn yield and that wet weather is beneficial. It shows also that if dry weather is also cool the result is generally favorable.

Correlation between weather factors.—Sometimes a weather factor seems to show a favorable or unfavorable effect upon the yield when in fact the real effect is due to another weather condition entirely, which itself determines the first factor.

It is sometimes true that wet weather is also cool weather or that wet and warm weather occur together over a district. To ascertain whether this is the case in the development of corn some correlations have been determined for Wauseon as given in Table 12.

TABLE 12.—*Results of correlation between thermal constants and rainfall, and also other factors, Wauseon, Ohio, 1883 to 1912.*

Correlation factors.	Correlation coefficient r.
(1) Thermal constants from date above ground to date of blossoming of corn and total rainfall for same period...	+0.42
(2) Thermal constants and total rainfall from date of blossoming of corn to date ripe....................................	+ .28
(3) Thermal constants and total rainfall from date of planting of corn to date that it is ripe...........................	− .11
(4) Thermal constants from date of planting of corn to date it is ripe and the total number of days in same period....	+ .37
(5) Relation of total number of days from date of planting of corn to date it is ripe and the yield of corn.............	− .001

The above values of r show that warm weather accompanies wet weather more than half of the time during the first part of the growth of corn, but that for the whole period any apparent relation is accidental.

RATE OF GROWTH OF CORN.

A number of years ago the Pennsylvania State Agricultural Experiment Station carried out some experiments showing the rate of growth of corn, and tables showing the results were published in their annual reports for 1887, 1888, and 1889.

The period covered in 1889 was from July 5 to 27, when the average rate of growth of corn was 139 thousandths of a foot in the daytime and 198 thousandths of a foot in the nighttime. In this discussion the "daytime" was for 9.5 hours, from 7:30 a. m. to 5 p. m., and the "nighttime" was from 5 p. m. to 7:30 a. m., or 14.5 hours. The hourly rate of growth during this period was 13.6 thousandths of a foot at night and 14.7 thousandths of a foot in the daytime.

Temperature data are given in the tables in connection with the rate of growth and from those tables figures 2 and 3 have been prepared. Figure 2 gives the general relation between the maximum temperature and the rate of growth in the daytime and indicates a close connection. Figure 3, however, indicates that the rate of growth of the corn plant at night follows along with and is very largely controlled by the minimum temperature.

Effect of minimum temperatures at Wauseon, Ohio.—With the curves in figure 3 in mind correlations were calculated between the minimum temperatures at Wauseon, Ohio, and the yield of corn. The results are given in Table 13.

TABLE 13.—*Results of correlation between mean minimum temperatures and corn yield, Wauseon, Ohio, 1883 to 1912.*

Correlation factor.	Correlation coefficient r.
(1) Mean minimum temperatures for 10 days before blossoming and yield	−0.01
(2) Mean minimum temperatures for 10 days after blossoming and yield	− .01
(3) Mean minimum temepratures from date corn appears above ground to date of blossoming and yield	− .07
(4) Mean minimum temperatures from date of blossoming to date corn is ripe and yield	+ .33

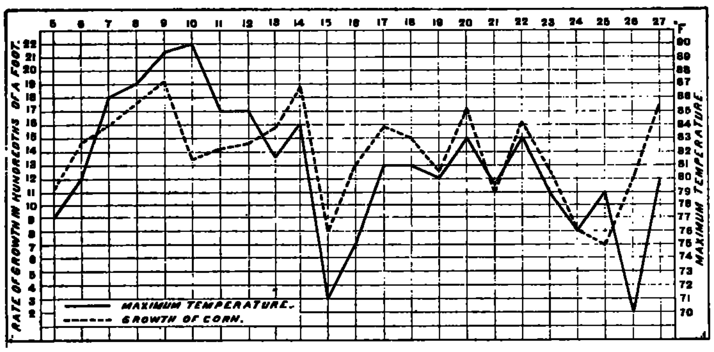

FIG. 2.—Relation between maximum temperature and daily growth of corn in Pennsylvania, July 5–27, 1889.

This shows no relation whatever between the minimum temperature and the yield of corn except during the period from the date of blossoming to date of ripening. This is rather low and we believe is entirely accidental, because the Pennsylvania experiments found that the vertical growth of corn practically ceases when the plants tassel out.

Effective rainfalls.—It is well known that small rainfalls during a drought may actually do more harm to a crop than good, because by merely wetting the surface of the ground an effective dust mulch may be destroyed and thus more water be lost to the crop by evaporation than has been gained by the shower.

Or numerous light showers during the early growth of the corn, by merely wetting the surface may cause it to root near the surface where the soil will quickly dry out during later dry spells. In our own investigations of accumulative effects of weather it was found that when July was quite dry the final yield was greater if the previous June was moderately dry also.

Of course the rate of growth and development of corn plants have been determined with certain definite amounts of water, in the laboratory. But to try and answer the often repeated question as to just what rainfall amounts are actually beneficial to the growing corn, or are most beneficial, we have adopted the following plan:

The rainfall for a definite district and period is multiplied by the total number of days with a certain amount of rain or more and divided by the whole number of days in the period. The equation is simple:

$$\frac{ab}{c},$$

where a is the total rainfall for the period, b the number of days with 0.10 inch, 0.20 inch, 0.30 inch, etc., rainfall or more, and c the total number of days in the period.

In Table 14 the effective rainfall was determined by taking the rainfall at Columbus, Ohio, for the 51-day period from June 21 to August 10, for 20 years, working out new factors in accordance with the formula as above, and correlating these new factors with the yield of corn in Franklin County, Ohio.

This method shows whether a certain amount of rain is as effective coming in many small showers, as it is in a few heavy showers, and it is accomplished by eliminating consideration of days with rainfalls below the definite amounts.

The general rule has been stated that for equal quantities of rain its value to agriculture increases as the number of rainy days diminishes, and on the other hand

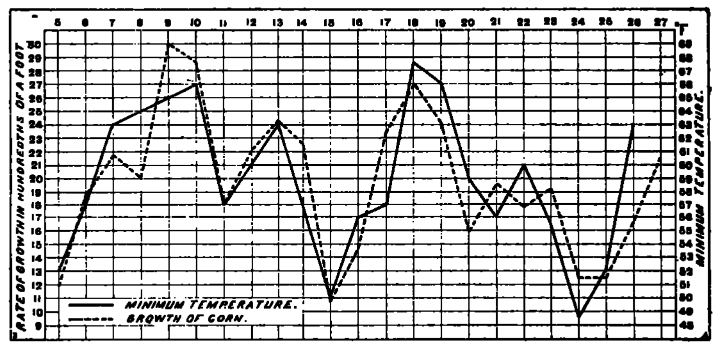

FIG. 3.—Relation between minimum temperature and nocturnal growth of corn in Pennsylvania, July 5–27, 1889.

diminishes as the number of rainy days increases. This can be true, however, only up to a certain point.

TABLE 14.—*Correlation table for determining the most effective rainfall in the yield of corn in Columbus and Franklin Counties, Ohio.*

Rainfall factors.	Correlation coefficient r.
Rainfall for July and yield of corn	+0.48
Rainfall, June 21 to August 10, and yield of corn	+ .60
Factor determined for the amounts given below as per formula and the yield of corn:	
Days with 0.01 inch or more	+ .61
Days with 0.10 inch or more	+ .61
Days with 0.20 inch or more	+ .61
Days with 0.25 inch or more	+ .64
Days with 0.30 inch or more	+ .59
Days with 0.40 inch or more	+ .61
Days with 0.50 inch or more	+ .70
Days with 0.60 inch or more	+ .55
Days with 0.70 inch or more	+ .56
Days with 0.75 inch or more	+ .57
Days with 0.80 inch or more	+ .38
Days with 0.90 inch or more	+ .59
Days with 1.00 inch or more	+ .41

This table shows quite plainly that rainfalls of 0.50 inch or more are the most effective in determining the yield.

For fear that the results might be affected by taking the rainfall at only one station, similar correlations have been calculated for the yields in Franklin, Madison, and Pickaway Counties, in central Ohio, and for the rainfall at all of the stations in and around those counties, 18 in all, for the period from July 21 to August 10. The results follow in Table 15.

TABLE 15.—*Results from correlations for most effective rainfalls, Central Ohio, 1891 to 1910.*

Correlation factors.	Correlation coefficient r.
Rainfall, July 21 to August 10, and corn yield (see Table 4)	+0.50
Factor determined for the amounts below as per formula and the yield of corn:	
Days with 0.01 inch or more	+.44
Days with 0.10 inch or more	+.51
Days with 0.20 inch or more	+.43
Days with 0.25 inch or more	+.49
Days with 0.30 inch or more	+.50
Days with 0.40 inch or more	+.47
Days with 0.50 inch or more	+.64

The differences in the correlation coefficients for the lower rainfall amounts are not great and could be purely accidental. But the higher value of r for 0.50 inch or more, corresponds to that determined in Table 14 and seems to show that one-half of an inch of rain is more beneficial than lesser amounts.

FOUR GREATEST CORN STATES.

Of the total acreage of corn in the United States 30 per cent is grown in the four States of Indiana, Illinois, Iowa, and Missouri. Of the total amount shipped out of the county in which it is grown 60 per cent is raised in these four States. The average area devoted to corn in these States is 30,325,300 acres. The average yield of corn is 32 bushels per acre.

The average rainfall has been correlated with the corn yield for these States for the period from 1888 to 1911, inclusive, with results as follows:

TABLE 16.—*Results of correlation of rainfall with the corn yield for Indiana, Illinois, Iowa, and Missouri, 1888 to 1911.*

Correlation factors.	Correlation coefficient r.
Rainfall for June and corn yield	+0.34
Rainfall for July and corn yield	+.73
Rainfall for August and corn yield	+.48
Rainfall for June and July and corn yield	+.68
Rainfall for July and August and corn yield	+.69
Rainfall for June, July, and August and corn yield	+.69

This shows that the rainfall for July has a greater effect upon the yield of corn than that for either June or July, or for a combination of these months with July.

An analysis of the rainfall and yield data in these States, as was made for Ohio, shows that the average increase in the corn yield with each increase of one-half inch in the rainfall in July amounts to 2 bushels per acre. This means a total increase in the corn yield of 61,000,000 bushels, worth thirty and one-half million dollars when corn is worth 50 cents per bushel.

In these four States when the rainfall for July has been between 2 and 2.5 inches the yield of corn has averaged 23 bushels per acre, and when the rainfall has been between 2.5 inches and 3 inches the yield has averaged 33 bushels per acre. This is an increase of 10 bushels per acre with an increase of only one-half inch of rain at the critical rainfall stage. But this increase amounts to the enormous quantity of 300,000,000 bushels, worth something like $150,000,000. This also means an increase in the value of the corn crop of $5 per acre when corn is worth 50 cents per bushel.

A correlation of the mean temperature in July over these four States with the yield of corn shows a negative relation amounting to -0.61. Investigation seems to show that this is due to the fact that cool weather usually accompanies rain in July.

Figure 4 explains this and shows the combined effect of rainfall and temperature differences upon the yield of corn in these four States in July. This indicates that warm and dry weather in July is always unfavorable, and that wet weather is usually favorable. Also that if the weather is dry a good crop is apt to be gathered, if it is cool also.

This chart explains that it is not warm weather alone that is unfavorable but high temperature coupled with dry weather.

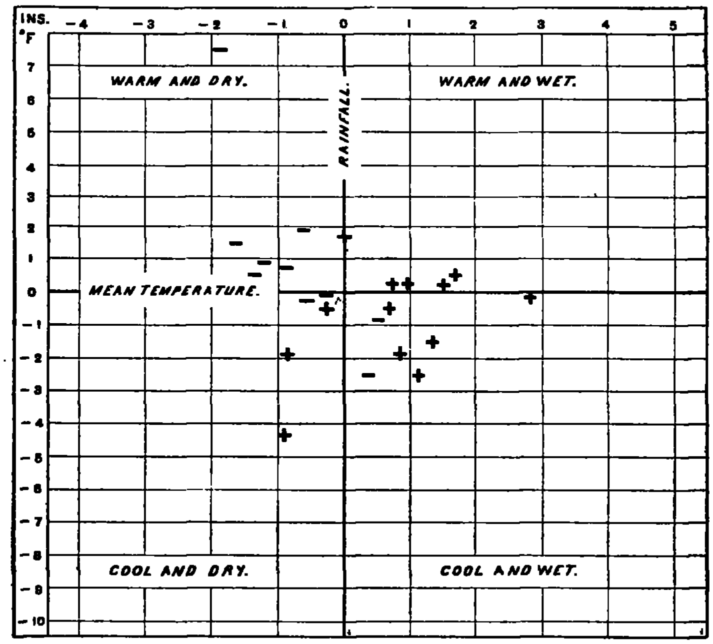

FIG. 4.—Dot chart showing combined effect of rainfall and mean temperature in July upon yield of corn. Averages for Indiana, Illinois, Iowa, and Missouri, 1888-1911. +, yield above normal; –, yield below normal.

Rainfall and corn yield in eight States.—In Table 17 is given the regular correlation table showing the relation between the average rainfall for the month of July and the yield of corn in bushels per acre over Ohio, Indiana, Illinois, Iowa, Nebraska, Kansas, Missouri, and Kentucky, for the past 25 years.

The correlation coefficient in this case is +0.78, while the probable error is only ±0.05. This is a very high correlation and indicates the high effect of the July rainfall alone when considering large districts.

An inspection of the table brings out the fact that an excess in the rainfall has always been followed by an excess in the corn yield. Also that a deficiency in the rainfall in July has been followed by a deficient yield every year except four, and in each one of these years the rainfall deficiency was slight.

The normal rainfall over these eight States in July is 3.9 inches, and the normal yield of corn 30 bushels per acre. The average area devoted to corn is close to 50,000,000 acres.

The yield of corn during those years when the rainfall averages one-half inch less than the normal or less has been 23 bushels per acre. On the other hand, when the rain has been one-half inch or more above the normal the yield has averaged 33 bushels per acre.

TABLE 17.—*Correlation of rainfall in July and the yield of corn for Ohio, Indiana, Illinois, Iowa, Nebraska, Kansas, Missouri, and Kentucky.*

Year.	July rainfall.			Corn yield.			3×6
1	2	3	4	5	6	7	8
	Amount.	Departure.	Square of departure.	Amount.	Departure.	Square of departure.	
	Inches.	*Inches.*		*Bushels.*	*Bushels.*		
1888	3.6	−0.3	0.09	32	+ 2	4	− 0.6
1889	4.9	+1.0	1.00	33	+ 3	9	+ 3.0
1890	2.1	−1.8	3.24	23	− 7	49	+12.6
1891	3.6	−0.3	.09	32	+ 2	4	− 0.6
1892	3.8	−0.1	.01	28	− 2	4	+ 0.2
1893	3.0	−0.9	.81	26	− 4	16	+ 3.6
1894	1.6	−2.3	5.29	20	−10	100	+23.0
1895	4.2	+0.3	.09	31	+ 1	1	+ 0.3
1896	6.4	+2.5	6.25	34	+ 4	16	+10.0
1897	3.6	−0.3	.09	26	− 4	16	+ 1.2
1898	3.5	−0.4	.16	29	− 1	1	+ 0.4
1899	3.8	−0.1	.01	30	+ 1	1	− 0.1
1900	4.6	+0.7	.49	31	+ 1	1	+ 0.7
1901	2.0	−1.9	3.61	18	−12	144	+22.8
1902	4.8	+0.9	.81	34	+ 4	16	+ 3.6
1903	3.8	−0.1	.01	29	− 1	1	+ 0.1
1904	4.4	+0.5	.25	30	+ 0.3	....	+ 0.2
1905	4.9	+1.0	1.00	35	+ 5	25	+ 5.0
1906	3.8	−0.1	.01	36	+ 6	36	− 0.6
1907	5.1	+1.2	1.44	30	+ 0.5	....	+ 0.6
1908	3.6	−0.3	.09	29	− 1	1	+ 0.3
1909	5.1	+1.2	1.44	31	+ 1	1	+ 1.2
1910	4.2	+0.3	.09	32	+ 2	4	+ 0.6
1911	2.8	−1.1	1.21	30	− 0.1	....	+ 0.1
1912	4.1	+0.2	.04	34	+ 4	16	+ 0.8
Sums	97.3	....	27.62	....	....	466	+88.4
Means	3.9	....	....	....	....	....	....

This means that when the rainfall for July averages less than 3.4 inches, the yield of corn over these eight States will average 10 bushels to the acre less than when the rainfall is more than 4.4 inches.

This is a difference of 500,000,000 bushels in the total yield of corn, and when corn is worth 50 cents per bushel the purchasing power of the farms in the central part of the United States is increased $250,000,000 through corn alone. Surely, corn is king.

Discussion of figures.

Each figure is explained by its head and legend. It will be well, however, to call attention to the fact that in Iowa and South Dakota the mean date of the beginning of corn harvest as shown by figure 9 is later than the average date of the first killing frost, as indicated in figure 7. In most other districts the corn harvest begins before killing frosts.

It would seem, therefore, that in calculating the length of the growing season to be from the date of planting to the date of harvesting we are considering too long a growing season in Iowa and South Dakota. This seems to be shown in the large number of growing days in figure 10, too high thermal constants in figure 11, too great an amount of rainfall in figure 13, and too great a number of possible hours of sunshine as shown in figure 14, in that particular district as compared with surrounding States.

This is particularly brought out in figure 12 by the low daily thermal constants in Iowa, especially as compared with other sections. It is quite probable that the end of the season should have been the average date of the first killing frost in the autumn, but inasmuch as the dates of beginning of planting and the beginning of harvest were used in other States, we have thought best to use the same data throughout.

In figure 15 the effect of the Great Lakes in causing an increased amount of cloudy weather is well shown.

In connection with these thermal constant and sunshine charts, reference should again be made to the sunshine-hour degree differences as stated on page 78 of this article. The whole study of thermal and sunshine constants is a most important one and can profitably be carried out more in detail.

CONCLUSIONS.

1. The controlling weather factor in the great corn-growing districts of the United States is rainfall.
2. The critical period of growth of corn during which favorable weather will cause a large crop and unfavorable weather a short crop, is comparatively brief.
3. If the rainfall for calendar months be considered, that for July has a far greater effect upon the corn yield than rainfall for any other month.
4. The rainfall from about the middle of July to the middle of August has a far greater effect upon the corn yield than that for any other period of similar length.
5. The rainfall for the 10 days following the date of blossoming has an almost dominating effect upon the yield of corn, the larger the rainfall the larger the yield.
6. If the rainfall is small during the 10 days after blossoming a high temperature has a very unfavorable effect upon the yield.
7. Rainfalls of one-half inch or more have a greater effect upon the development of corn than falls of less amount.
8. It seems possible to give a close estimate of the probable yield of corn by August 10, by careful study of the weather conditions that have prevailed up to that time.
9. The importance of shallow cultivation after each rainfall in July, and after August 1 for the purpose of forming a dust mulch and thus preventing the loss of water by evaporation, can not be overestimated.
10. The science of agricultural meteorology can be advanced, and the results of these investigations be made of more practical value to the farmer, by a detailed study of the critical periods of growth and the weather factors most affecting the yield of other field and garden crops.

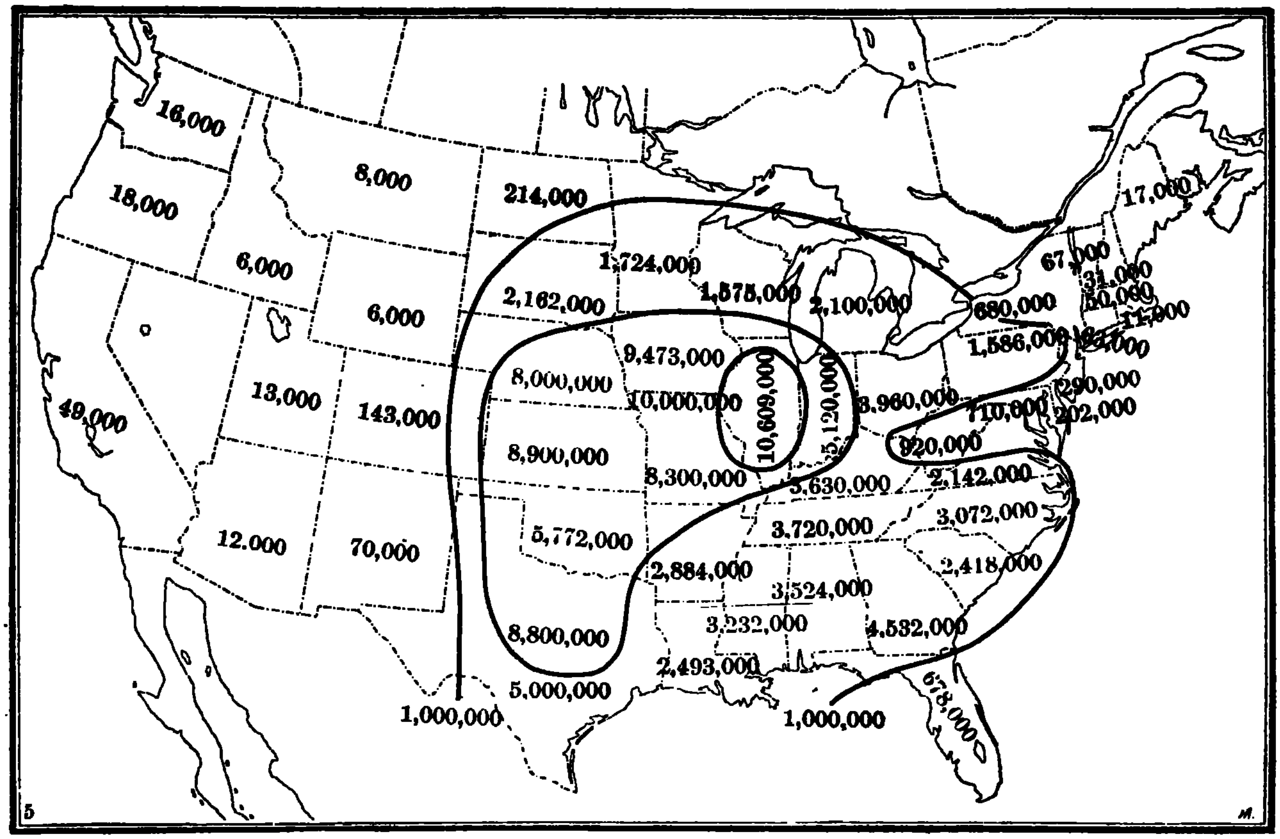

FIG. 5.—Number of acres planted to corn in each State in 1910.

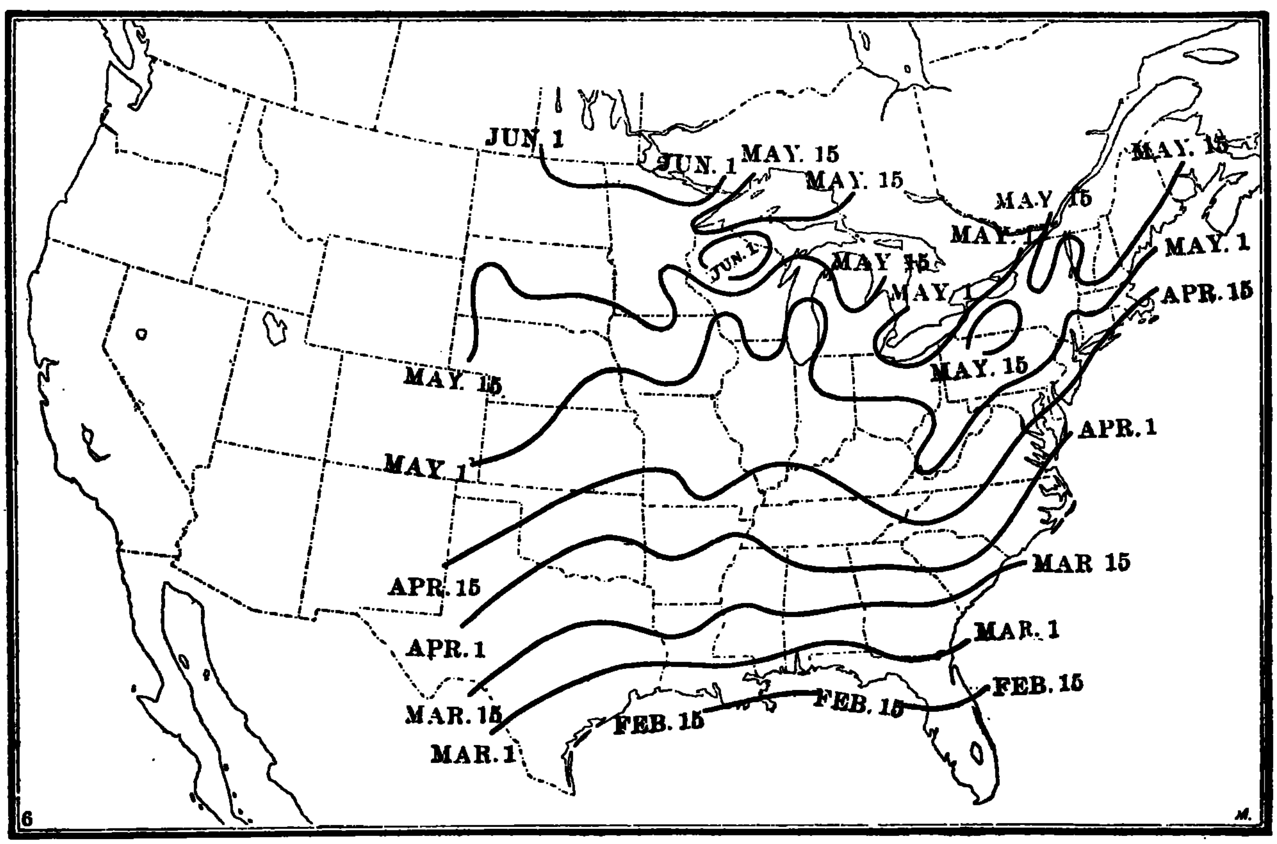

FIG. 6.—Average date of last killing frost in spring. (From Weather Bureau Bulletin V.)

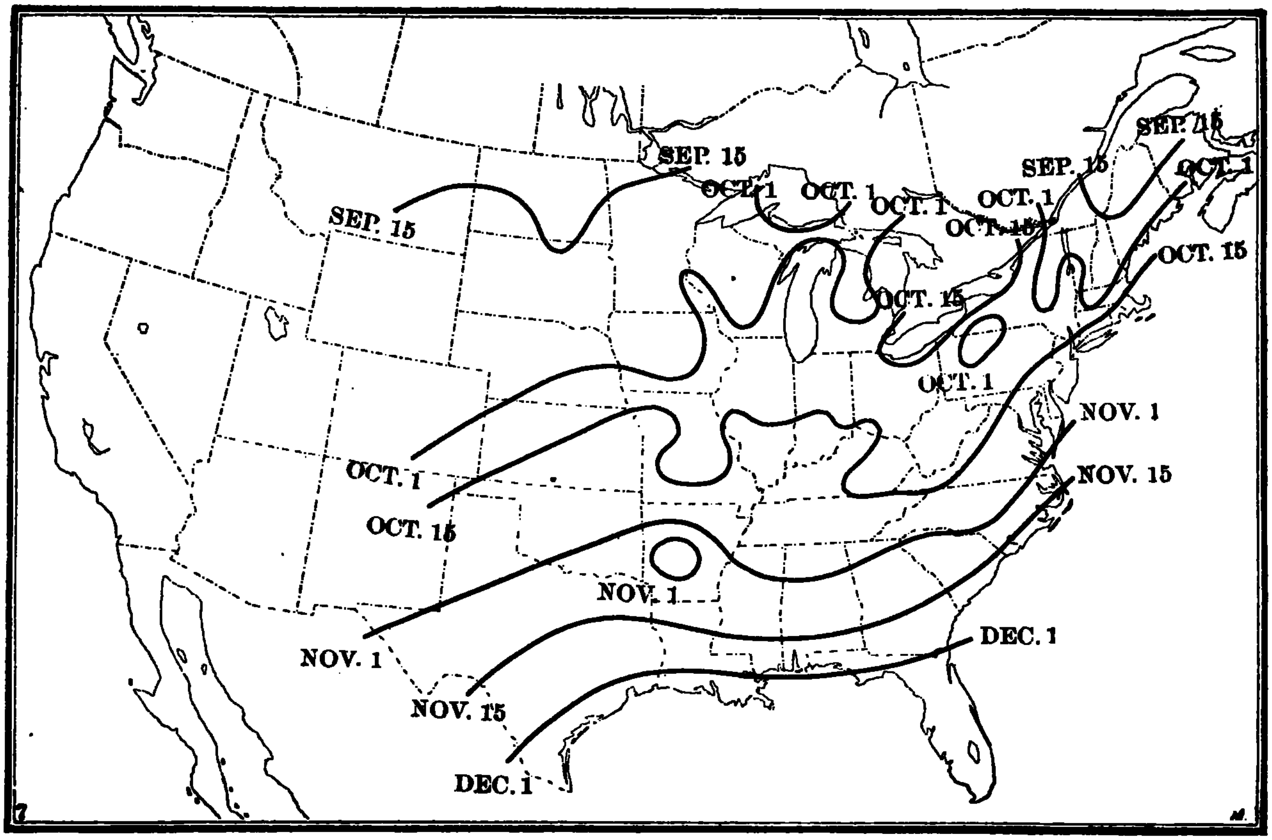

FIG. 7.—Average date of first killing frost in autumn. (From Weather Bureau Bulletin V.)

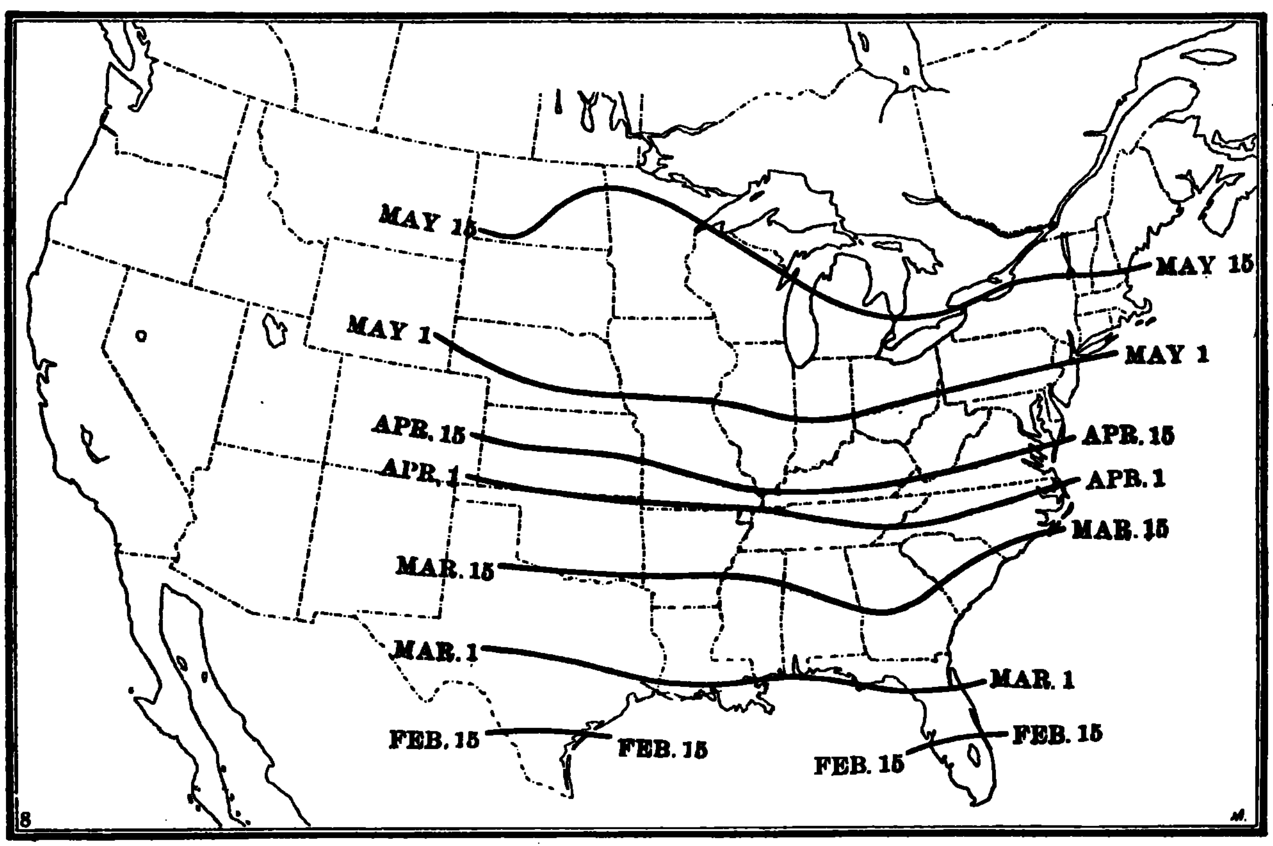

FIG. 8.—Average date when corn planting begins. (From Bureau of Statistics Bulletin 85.)

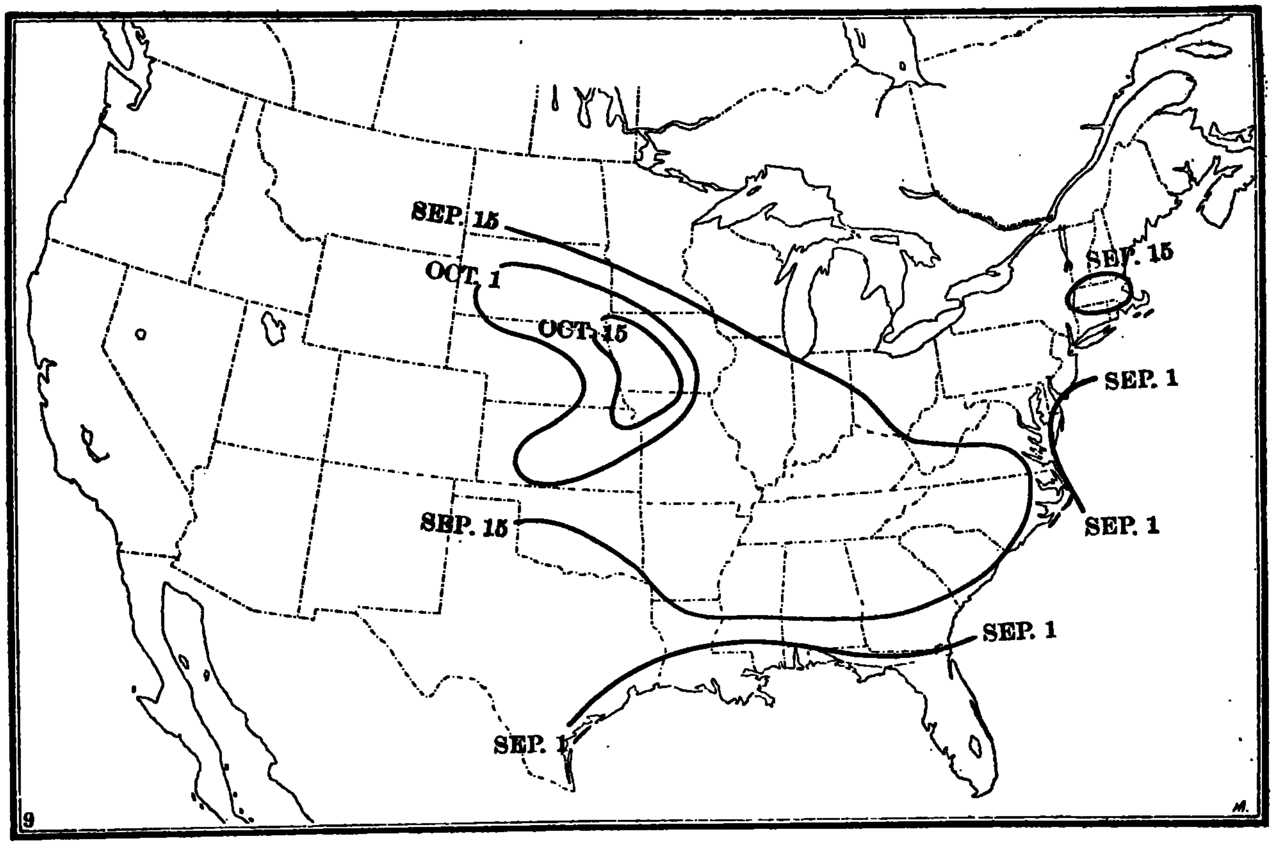

FIG. 9.—Average date when corn harvesting begins. (From Bureau of Statistics Bulletin 85.)

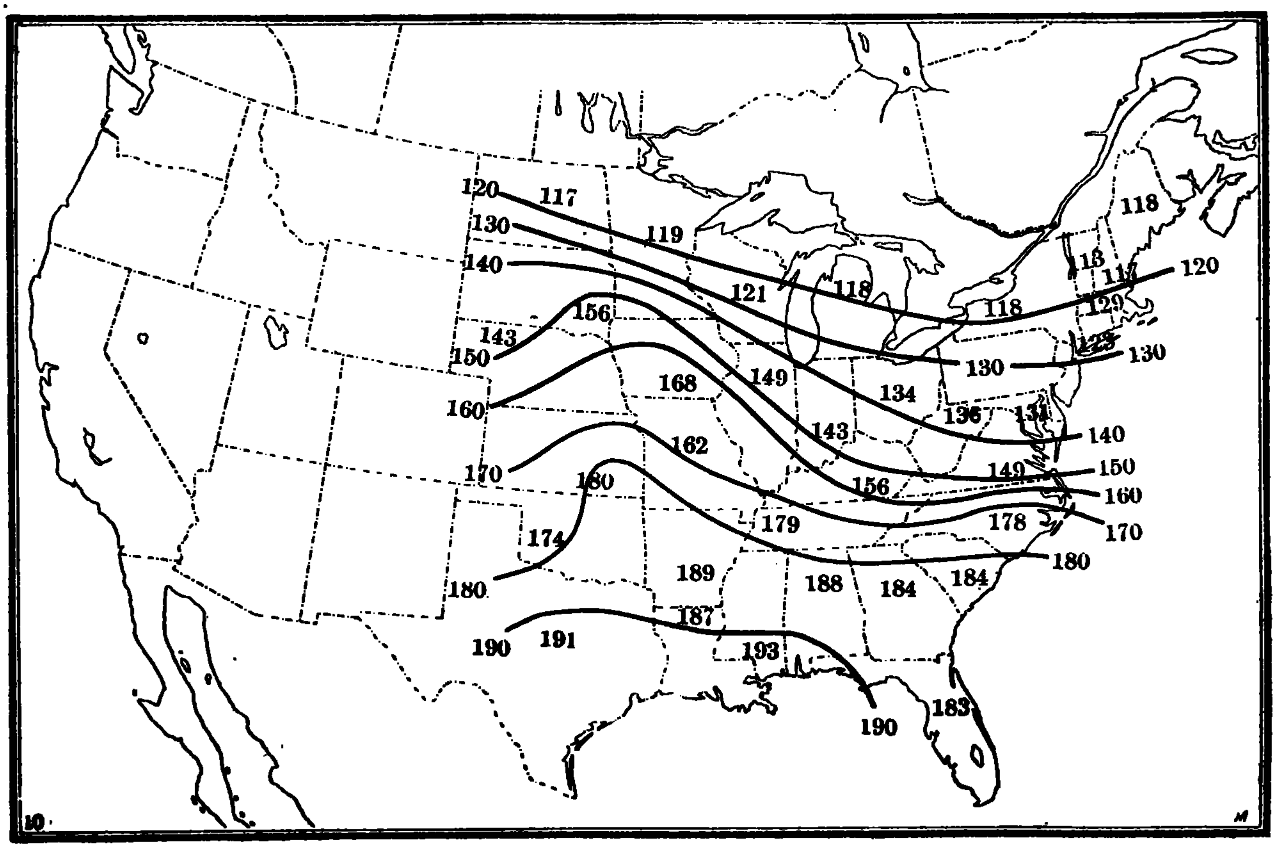

FIG. 10.—Average number of days between planting and harvesting corn. Figures show averages for the whole of each State.

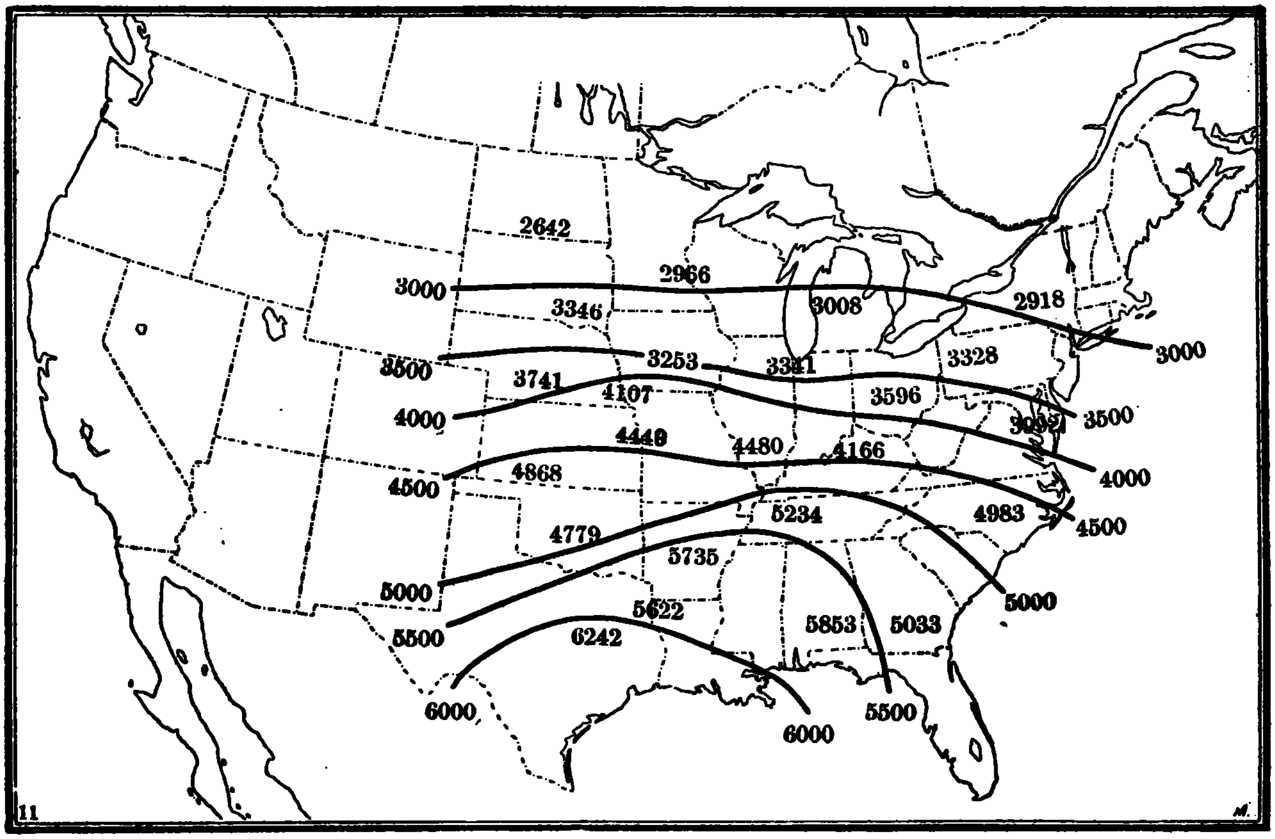

FIG. 11.—Average thermal constants between planting and harvesting corn. Figures show sums of daily mean temperatures above 43° F. during growth and maturing of the corn plant.

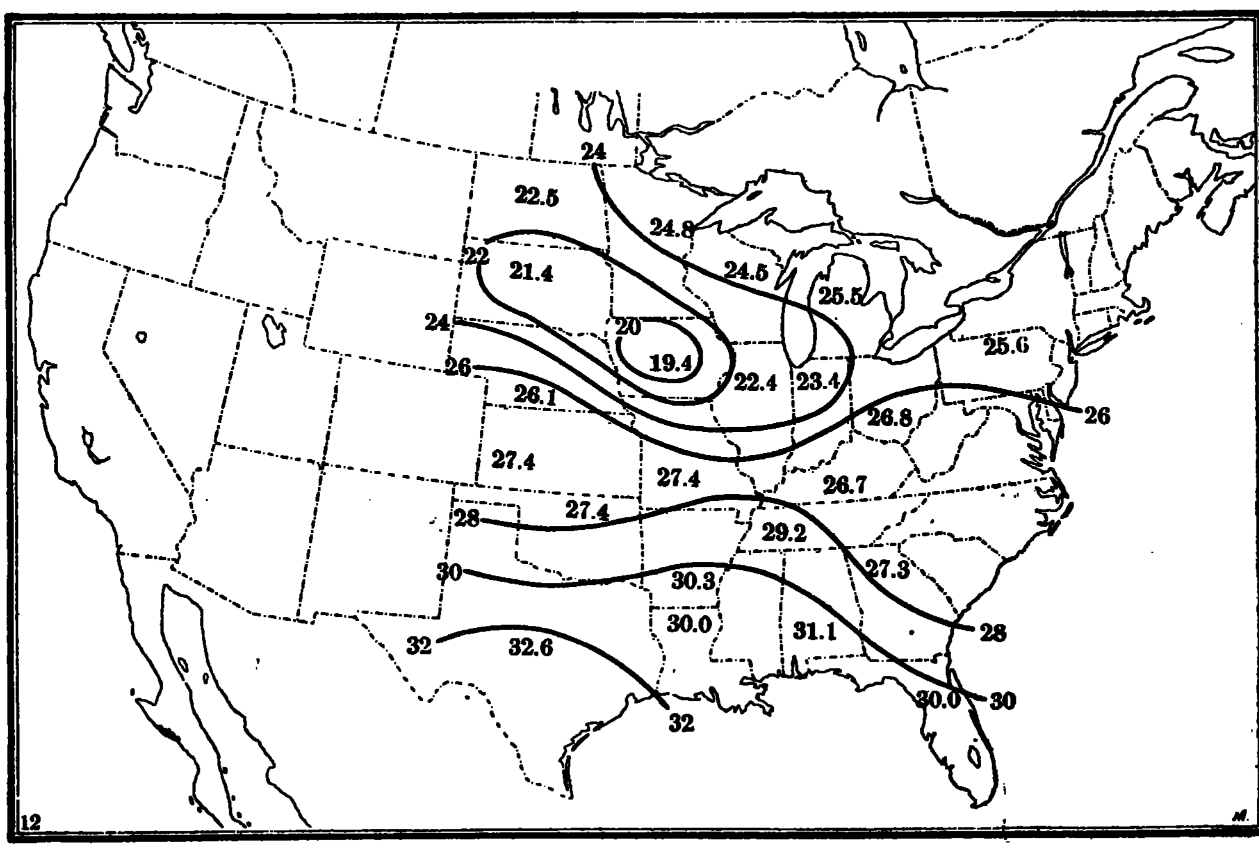

FIG. 12.—Average daily thermal constant between planting and harvesting corn.

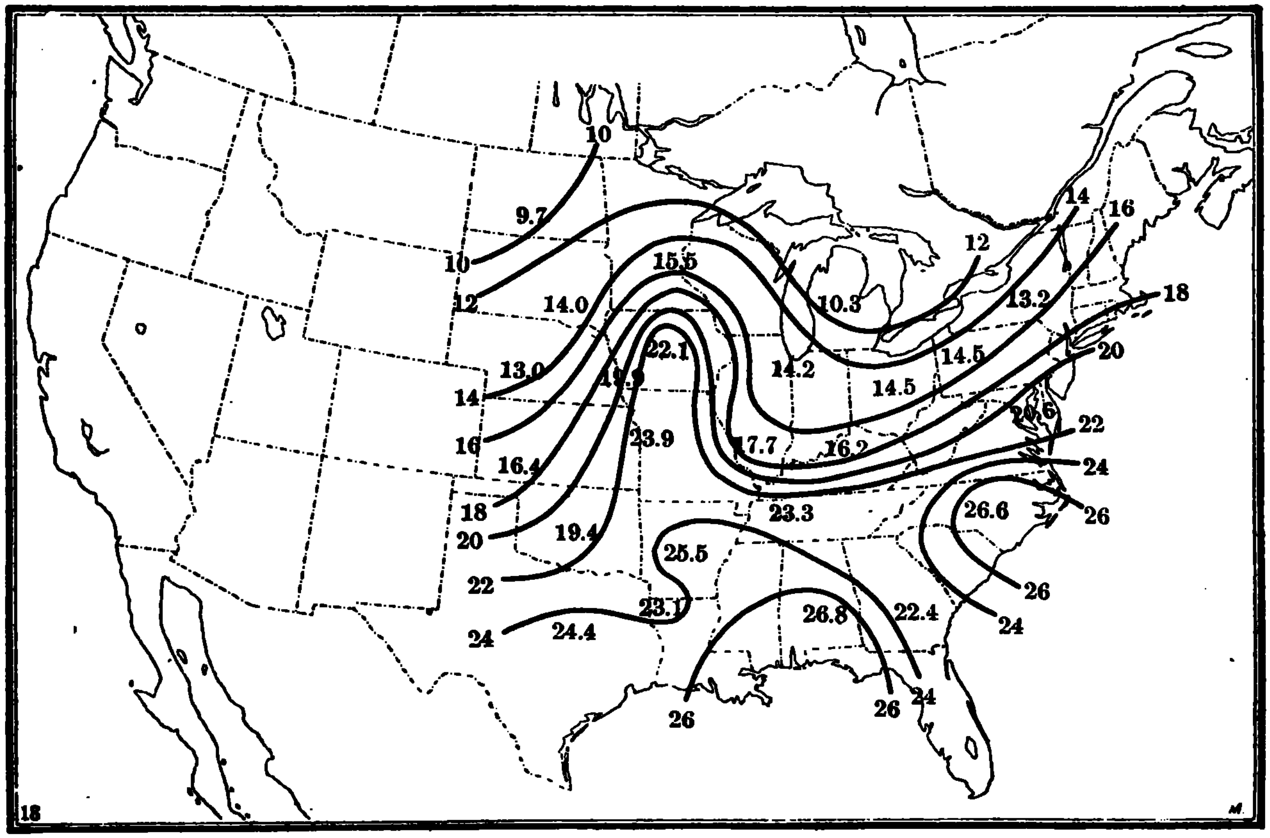

FIG. 13.—Rainfall constants from planting to harvesting of corn. (Average total rainfall during the growth and maturing of the corn plant.)

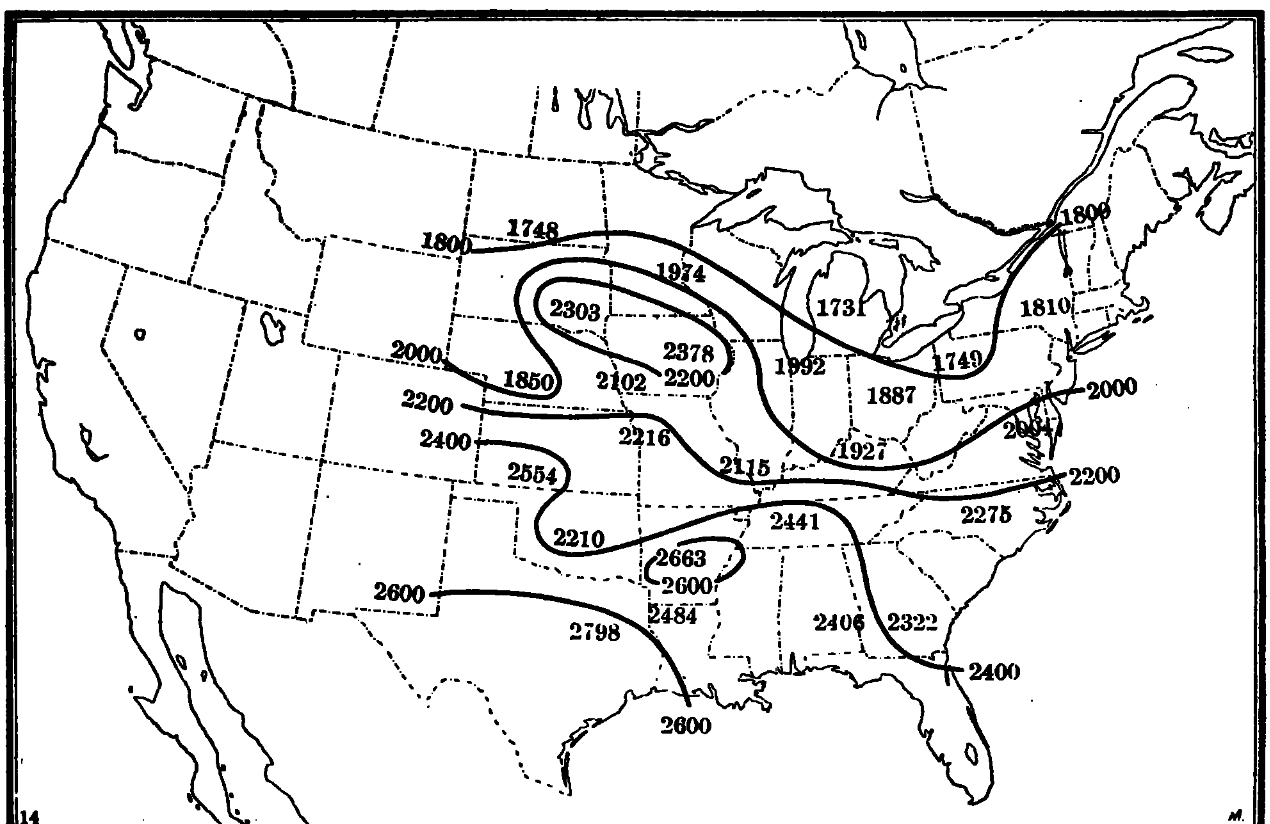

FIG. 14.—Total possible hours of sunshine between planting and harvesting of corn.